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(54) **Torque measurement apparatus**

(57) Apparatus for measuring torque transmitted in a rotating component 10 includes two series 11, 12 of alternate reflective and non-reflective areas spaced from each other along the rotational axis of the component. Each series of areas is disposed around the rotational axis and fibre optic means 15—18 directs a beam of light from a remote light source 19 onto the series of areas and receives pulses of light reflected by the reflective areas. The pulses of reflected light from each of the series of areas are converted 20 into electrical wave forms and comparison 21 of the phase relationship of the electrical wave forms is processed to provide a value of torque.

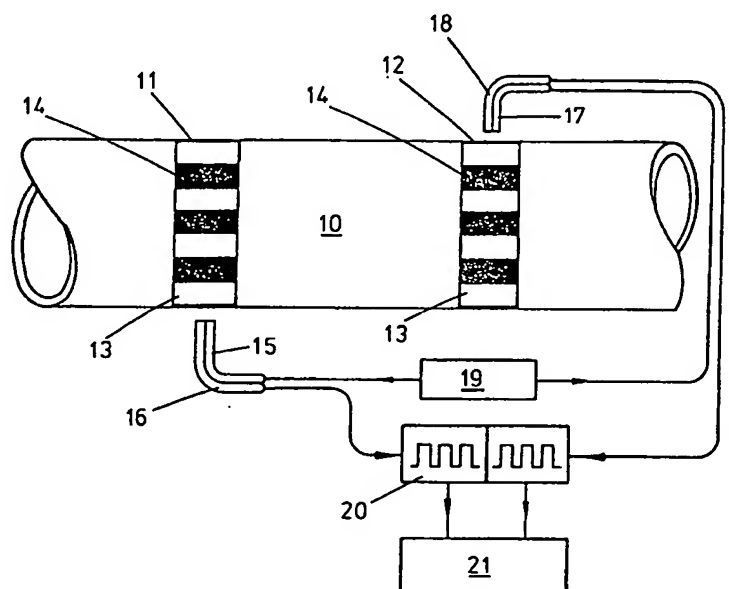

FIG.1

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy

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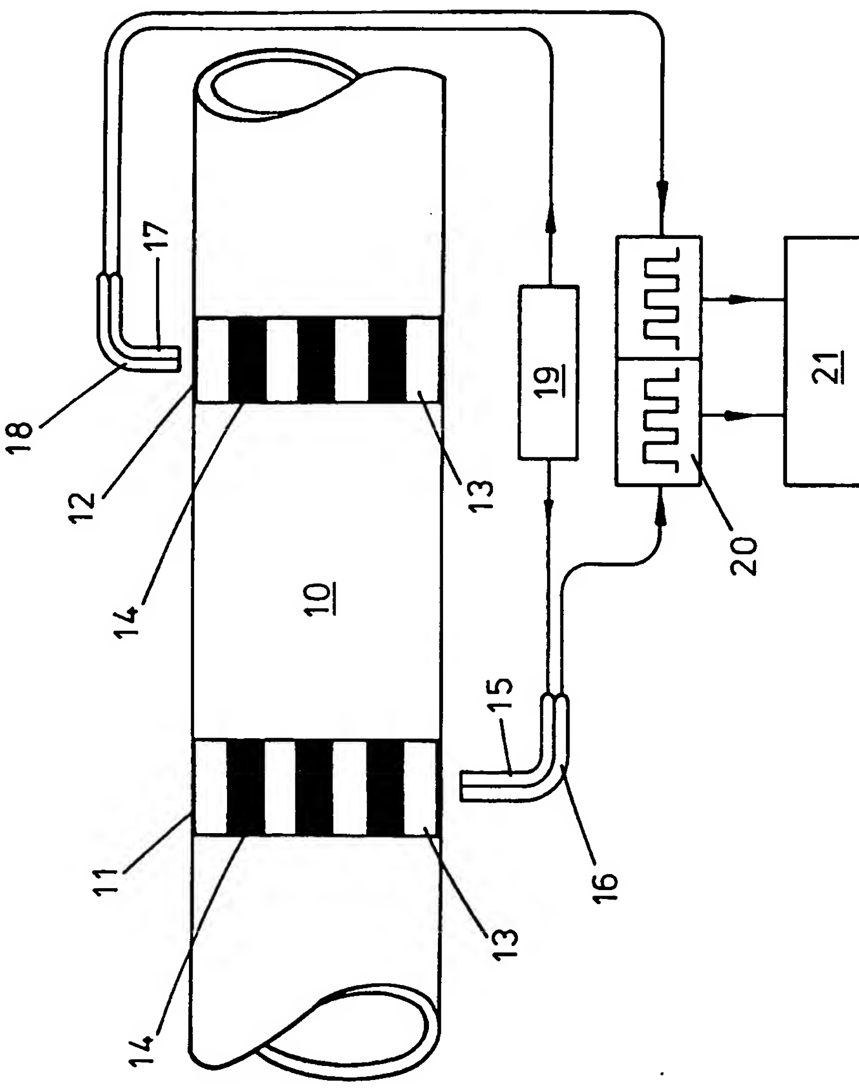

FIG.1

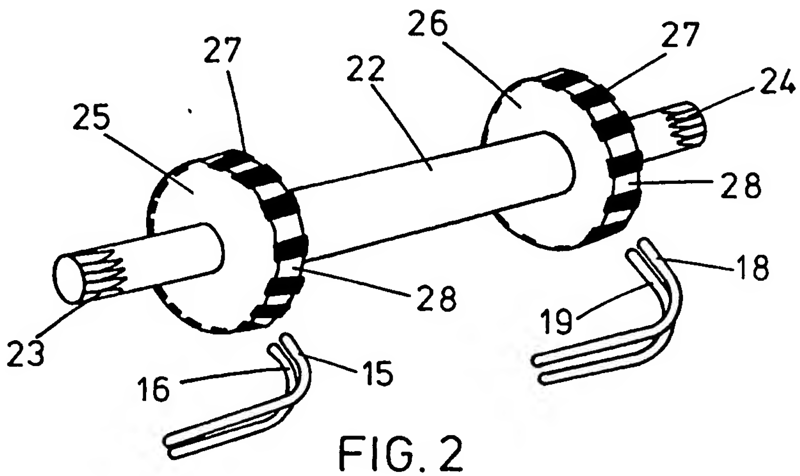

FIG. 2

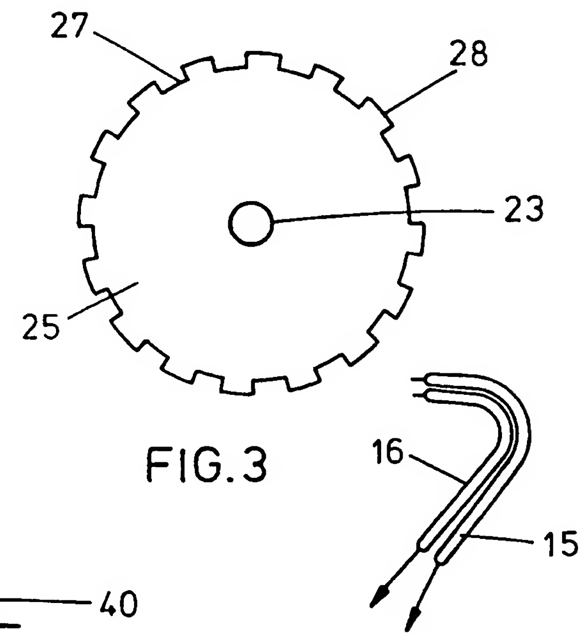

FIG. 3

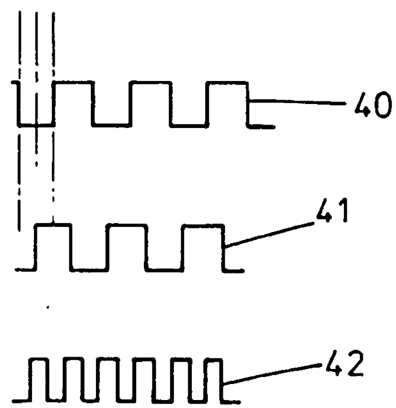

FIG. 4

SPECIFICATION

Torque measurement apparatus

This invention relates to apparatus for measuring torque, and is particularly concerned with apparatus for measuring torque in dynamic components.

The use of an electrical strain gauge bridge for measuring the torque transmitted by a rotating component such as a shaft is well known. However, a problem arises in the transfer of electrical power to the strain gauge bridge which is mounted on the shaft and in the take-off of the bridge output.

An optical torquemeter employing a light beam to sense torsional shear strain in a rotating shaft has been proposed, one such torquemeter comprising two disc members mounted concentrically on a shaft for rotation therewith. Each disc has a plurality of apertures so that it acts as a rotating light shutter to a beam of light directed parallel to the axis of rotation of the shaft. The discs are mounted with their apertures in alignment in a 'no torque' condition and pulses of light from a light source mounted near to the shaft on one side of the discs are recieved by a light sensing device positioned at the other side of the discs as aligned apertures pass the light source. When the shaft is rotating and transmitting torque, the torsional shear strain in the shaft causes angular movement of the discs relative to each other by an amount which is proportional to the torsional shear strain. This modulates the pulses of light received by the light sensing device which is generally a photo-electric device that converts the light pulses into a series of electrical pulses. Whilst the electrical pulses will vary with both torque and speed, the mark/space ratio at any given shutter aperture remains constant irrespective of rotational speed and varies only with aperture changes, i.e. with torque, so that the average electrical signal which can be presented by meter or other means is, after calibration, a measure of the torque being transmitted by the shaft.

One difficulty with this arrangement is that of positioning the light source and the light sensitive device close to the shaft so that they are in alignment with each other in a direction parallel to the axis of rotation of the shaft. A disadvantage of the arrangement is that of pickup of local noise interference, such as static produced by shaft rotation, by signal output wiring leading from the light sensitive device which generally comprises a photo-electric cell. Unless the output wiring can be adequately screened it may be necessary to accommodate signal processing equipment close to the shaft.

According to the present invention apparatus for measuring the torque transmitted by a rotary component during rotation thereof comprises two series of alternate reflective and non-reflective areas each disposed around the axis of rotation of the component and respectively positioned thereon to be subject to relative rotational displacement by torque transmitted by the component; fibre optic means for transmitting light towards each series of areas and for receiving and transmitting pulses of light reflected from each series of areas; means for converting into electrical wave forms the pulses of light transmitted from the respective series of areas; and means for comparing the phase relationship of the electrical wave forms to provide an indication of torque transmitted by the component.

In an embodiment of the invention, the component may comprise a torquemeter shaft adapted for connection between rotating components in a dynamic system.

The reflective and non-reflective areas may be provided on the surface of the component and, generally, the dimensions of the reflective and non-reflective areas will be equal and will be such as to provide good resolution between pulses of reflected light when the component is rotating at maximum speed.

When the component comprises a torquemeter shaft the two series of alternate reflective and non-reflective areas may be provided on the circumferential or radial surfaces of two flanges raised from the shaft.

However, when the torque required to be measured is that in a large dynamic component such as, for example, a rotating shaft in the transmission system of a ship, the two series of alternate reflective and non-reflective areas may be provided on split collars having clamping means whereby they may be secured to a shaft in suitably spaced relationship to each other.

The reflective and non-reflective areas may be disposed on a circumferential or a radial surface of such a collar.

The alternate reflective and non-reflective areas may be produced by any suitable means, for example, the reflective areas may be produced by grinding and/or polishing and the non-reflective areas may be produced by etching and/or painting the surface of the rotating component.

The fibre optic means preferably comprises a twin-core optical fibre associated with each of the series of alternate reflective and non-reflective areas. One core is arranged to transmit light from a light source to the associated series of reflective and non-reflective areas and the other core is arranged to receive pulses of light reflected by the reflective areas of that series to transmit these light pulses to the means for converting them into electrical wave form.

The means for converting transmitted reflected light pulses into an electrical wave form may comprise a photo-electric cell.

Whilst other forms of light source may be used it is advantageous to use laser light, which may be pulsed, because this permits long fibre optic transmission paths to be employed so that the means for converting the light pulses into electrical wave forms and the means for comparing the phase relationship of the electrical wave forms

can be located remote from the rotating component in a 'clean' zone.

Two embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:—

Figure 1 is a diagrammatic representation of torque measuring apparatus in accordance with an embodiment of the invention in which two series of reflective and non-reflective areas are provided on a rotatable shaft;

Figure 2 shows a torquemeter in accordance with another embodiment of the invention having series of reflective and non-reflective areas provided on raised flanges:

Figure 3 is a view looking on one end of the torquemeter shown in Figure 2; and

Figure 4 shows electrical wave forms derived from pulses of light reflected by two series of reflective and non-reflective areas, and also shows a wave form derived by comparing their phase relationship.

In the embodiment of Figure 1 a rotatable component comprising a power transmission shaft 10 (shown in part) has two series 11 and 12 of alternate reflective and non-reflective areas 13 and 14, respectively, on the circumferential surface thereof. The series of areas 11 are spaced from the series of areas 12 along the axis of rotation of the shaft 10, and each reflective area 13 and non-reflective area 14 in the series 11 is aligned with a respective reflective area 13 and nonreflective area 14 in the series 12 in a direction parallel to the axis of rotation. The reflective areas 13 are produced by grinding and polishing the shaft whilst the non-reflective areas 14 are produced by etching providing this is not detrimental to the fatigue strength of the material from which the shaft is manufactured, and hence to the fatigue life of the shaft, in which case they may be provided by coating the areas 14 with a matt black paint or other suitable non-reflective coating material. The arcuate lengths of the reflective areas 13 and nonreflective areas 14 are equal and are such as to ensure good resolution between pulses of light reflective by the areas 13 when the shaft is rotating at maximum speed.

Two optical fibres 15 and 16 each have one end positioned to face the series of areas 11 and two similar optical-fibres 17 and 18 each have one end positioned to face the series of areas 12. Fibres 15 and 17 have their other ends positioned for receiving light from a pulsed laser 19, and transmit the laser light to their ends adjacent the series of areas 11 and 12, from which ends the laser light is directed at the areas 11 and 12. When the shaft 10 is rotating light is reflective by the reflective areas 13 but little or no light is reflected by the non-reflective areas 14 so that each of the series of areas 11 and 12 produces pulses of reflected light. These pulses of reflected light are received by the fibres 16 and 18 and are transmitted to means for converting them into electrical wave form which in this embodiment comprises a twin photo-electric cell 20.

The electrical wave forms produced by the twin photo-electric cell 20 for each train of reflected light pulses from the areas 11 and 12 are passed to comparator means 21 where their phase relationship is compared and after suitable processing is presented as a reading of torque being transmitted by the shaft 10.

In the embodiment of Figures 2 and 3, a rotatable component comprising a torquemeter shaft 22 is adapted for installation between rotatable components in a transmission system (not shown) by splined ends 23 and 24. Two flanges 25 and 26 are formed integrally with the shaft 22 and are spaced from each other along the length of the shaft. The circumferential surface of each flange 25 and 26 is formed with a plurality of undercut portions 27 of equal arcuate length to raised portions 28 between which they are formed. The undercut portions 27 of the flange 25 are aligned with the undercut portions 27 of the flange 26 in a direction parallel to the axis of rotation, and the bottom and side surfaces of all undercut portions 27 are coated with a matt black paint or similar non-reflective coating whilst the arcuate surface of each raised portion 28 is polished to produce a highly reflectve surface.

As in the embodiment of Figure 1, two optical fibres 15 and 16 are positioned by mounting means (not shown) so that one of their ends faces the reflective and non-reflective areas on the circumferential surface of the flange 25, and two optical fibres 17 and 18 are positioned so that one of their ends faces the reflective and non-reflective areas on the circumferential surface of the flange 26. The opposite ends of the fibres 15 and 17 are again positioned for receiving light from a laser light source (not shown), and the opposite ends of the fibres 16 and 18 are positioned for transmitting pulses of light reflected by the reflective areas of the flanges 25 and 26 to a twin photo-electric cell (not shown) which converts them into electrical wave forms. These wave forms are then fed to comparator means (not shown) where the phase relationship is compared. In this embodiment the undercut portions 27 provide an accurate machined division between the reflective and non-reflective areas so that a sharp optical separation is obtained between these areas.

In operation of the embodiments of the invention hereinbefore described with reference to Figure 1 and with reference to Figures 2 and 3, rotation of the shaft 10 or the torquemeter shaft 22 produces a train of pulses of reflected light from each of the series of reflective and non-reflective areas as the reflective areas pass the ends of the optical fibres. Each train of pulses of reflected light is converted into square wave form by the twin photo-electric cell and when the shaft is rotating under zero-torque conditions the electrical wave forms derived from the pulses of light reflected by two series of reflective and non-reflective areas will be in phase and there will be no output from the comparator means. However, when the shaft is rotating under load and, therefore, subject to

torque, the reflective areas of one series of areas will move out of alignment with the reflective areas of the other series of areas, the electrical wave forms derived therefrom will be out of phase with each other as is shown in Figure 4, in Figure 4 the wave form 40 is that derived from the series of areas nearest the drive source of power input (not shown) and may be regarded as the measurement datum, whilst the wave form 41 is that derived from the second series of areas, furthest from the drive source or power input. The wave form 41 will be seen to lag behind the wave form 40, this being representative of the effect of torsional loading of the shaft. Processing of the wave forms 40 and 41 may take several forms depending upon the extent of the information (i.e. torque plus speed and/or power) to be presented. For torque presentation alone 'summing the differences' is a typical process and in Figure 4 wave form 2 is the resultant of such a summation of wave forms 40 and 41 made ready for presentation by suitable means.

It will be noted that in the embodiment of Figure 1 the two optical fibres 15 and 16 are positioned at the opposite side of the shaft 10 from the two optical fibres 17 and 18, whereas in the embodiment of Figures 2 and 3 they are positioned on the same side of the torquemeter shaft 22. This illustrates one advantage of the present invention in that the two pairs of optical fibres do not have to be in alignment along the length of the shaft providing they are each aligned with respective reflective areas or non-reflective areas of their respective series of areas in a datum position.

With an arrangement as described and illustrated in the embodiment of Figure 1, or in the embodiment of Figures 2 and 3, wherein the reflective and non-reflective areas are of equal arcuate dimension and reflective and non-reflective areas of one series of areas are in alignment with respective reflective and non-reflective areas of the other series of areas, the present invention has the advantage that torque may be measured in either direction of rotation.

By employing optical fibres between the light source and the shaft, and between the shaft and light sensing and processing means, the present invention avoids the problem of noise pick-up. By employing a high-intensity light source such as a pulsed laser, optical fibres of considerable length may be employed to allow processing equipment to be located in a 'clean' zone whilst maintaining strong signal inputs.

In a non-illustrated modification of the embodiments of Figure 1 and Figures 2 and 3, the two optical fibres 15 and 16 and the two optical fibres 17 and 18 may be replaced by twin-core optical fibres at least over that part of their lengths which are immediately adjacent to the reflective and non-reflective areas.

In a non-illustrated embodiment of the invention the two series of alternate reflective and non-reflective areas are provided on split collars having clamping means whereby they may be secured to a shaft in spaced relationship to each other and with their reflective and non-reflective areas aligned in a direction parallel to the rotational axis of the shaft.

Claims

1. Apparatus for measuring the torque transmitted by a rotary component during rotation thereof, comprising two series of alternate reflective and non-reflective areas each disposed around the axis of rotation of the component and respectively positioned thereon to be subject to relative rotational displacement by torque transmitted by the component; fibre optic means for transmitting light towards each series of areas and for receiving and transmitting pulses of light reflected from each series of areas; means for converting into electrical wave forms the pulses of light transmitted from the respective series of areas; and means for comparing the phase relationship of the electrical wave forms to provide an indication of torque transmitted by the component.

2. Apparatus as claimed Claim 1, wherein the component comprises a torquemeter shaft adapted for connection between rotating components in a dynamic system.

3. Apparatus as claimed in Claim 1 or Claim 2, wherein the two series of alternate reflective and non-reflective areas are provided on the surface of the component.

4. Apparatus as claimed in Claim 3, wherein the two series of alternate reflective and non-reflective areas are provided on two cylindrical flanges raised from the component.

5. Apparatus as claimed in Claim 4, wherein the two series of alternate reflective and non-reflective areas are disposed on circumferential surfaces of the cylindrical flanges.

6. Apparatus as claimed in Claim 5, wherein the non-reflective areas are disposed on segments of the circumferential surface of each cylindrical flange which are undercut with respect to the segments of the circumferential surface on which the reflective areas are disposed.

7. Apparatus as claimed in any one of the preceding claims, wherein the reflective areas are produced by grinding and/or polishing and the non-reflective areas are produced by etching and/or painting.

8. Apparatus as claimed in any one of the preceding claims, wherein the fibre optic means associated with each said series of areas comprises a twin-core optical fibre.

9. Apparatus as claimed in any one of the preceding claims, wherein the means for converting transmitted reflected light pulses into an electrical wave form comprises a photo-electric cell.

10. Apparatus as claimed in any one of the preceding claims, including a laser supplying light to the fibre optic means for transmission to said series of areas.

11. Torque measurement apparatus substantially as hereinbefore described with

reference to and as shown in Figure 1 of the accompanying drawings.

12. Torque measurement apparatus substantially as hereinbefore described with reference to and as shown in Figures 2 and 3 of the accompanying drawings.

13. Every novel feature and every novel combination of features disclosed herein.

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